INDIVIDUAL WELL REPORT FROM THE PROGRAM ON

CHARACTERIZATION AND ANALYSIS OF DEVONIAN SHALES AS RELATED TO RELEASE OF GASEOUS HYDROCARBONS

WELL C-338 WISE COUNTY, VIRGINIA

by

R. S. Kalyoncu, J. P. Boyer,
and M. J. Snyder

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INTRODUCTION AND SUMMARY

Battelle-Columbus Laboratories continues to submit Individual Well Reports on the Eastern Gas Shales Project. Results and their analyses on all six tasks are reported on the C-338 Well (Wise County, Virginia). Samples from the C-338 well were cored between depths of 4870 and 5475 feet. A total of 81 samples were obtained. Considerably high hydrocarbon gas contents are observed (average hydrocarbon gas content in the canisters was 63.1 percent). Higher chain hydrocarbon gases are also present in significant quantities. Average hydrocarbon gas volume per unit volume of shale is 1.2.

Gas release kinetics studies on C-338 shales reveal diffusion coefficients in the order of 10^{-7} cm^2/sec., which agree well with values of other shales.

Excellent one-to-one correlations exist between the chemical characteristics (carbon, hydrogen contents) and hydrocarbon gas contents. Increasing carbon and hydrogen values are associated with higher hydrocarbon gas contents.

Among the physical characterization data, densities are inversely related to organics contents, increasing the hydrocarbon gas contents.

OBJECTIVE AND SCOPE

The objective of this program is to determine the relationships between shale characteristic, hydrocarbon gas content, and well location to provide a sound basis for defining the productive capacity of the Eastern Devonian Shale deposits and for guiding research, development, and demonstration projects to enhance the recovery of natural gas from the shale deposits. The program includes a number of elemental tasks as a part of the Resource Inventory and Shale Characterization subprojects of DOE's Eastern Gas Shales Project and is designed to provide a wide variety of support data for that project.

A large number of core samples of gas bearing Eastern Devonian Shale will have been examined by the end of the program. After the characterization data for individual wells have been compiled, attempts will be made to establish the interrelationships between the shale characteristics, the hydrocarbon gas content, and well locations from which the samples were obtained, employing the Automatic Interaction Detection (AID) Analysis.

The following tasks comprise the total efforts in this research program:

Task	Descriptive Title
1	Core Sampling
2	Gas Content and Gas Release Kinetics
3	Chemical Characterization of Shale
4	Physical Characterization of Shale
5	Lithology of Shale
6	Data Interpretation and Correlation

A. ANALYSIS AND DISCUSSION OF THE CHARACTERIZATION DATA

Detailed descriptions of the experimental procedures employed in the execution of the elemental tasks described were reported in the Appendix of the Fifth Quarterly Technical Progress Report (ORO-5205-5) submitted to U.S. DOE in January 1978.

Task 1. Core Sampling

The C-338 shales (Wise County, Virginia) were cored and canned in May 1977. Coring was begun at 4870 feet and stopped at 5475 feet. Eleven barrels of core were sampled. Forty samples were collected for Battelle and 41 samples were collected for other DOE contractors. More detailed coring information is presented in Table 1. Additional well data, namely color codes and on-surface times, on C-338 shales are tabulated in Table 2 as field sampling data. Figure 1 is a plot of on-surface time for all C-338 shales.

Task 2. Gas Contents and Release Rates

Initial gas release data on C-338 shale are summarized in Tables 3 and 4. Table 3 exhibits the hydrocarbon gas analysis of the free space in the sealed canisters along with nitrogen, oxygen, and carbon dioxide. Present hydrocarbon gases are methane through pentane, methane being the major hydrocarbon gas. Considerable amounts of higher hydrocarbons, however, (C_2 - C_5) are also present. The quantity of higher hydrocarbons is a measure of BTU quality of the gas, as gases C_2 through C_5 have higher caloric values than methane gas. The C-338 well is one of the highest gas content wells among the wells sampled in the Eastern Gas Shales project.

Table 4 is a statistical summary of the gas data presented in Table 3. Average value of hydrocarbon gases in this well is 63.1 percent with upper and lower limits being 69.4 and 57.8, respectively. Average gas volume per unit volume of shale is 1.2.

Figure 2 is a plot of hydrocarbon gas contents as a function of sample depth. Two distinct zones can be seen in this plot; where, between 4875 and 5000 feet, a decrease in hydrocarbon gas content with depth is apparent, and between depths of 5175 and 5475 feet hydrocarbon gas contents increase with depth.

In terms of kinetics studies, both microbalance weight loss experiments and continuous flow measurements were conducted on two different C-338 shale samples. Figure 3 summarizes the weight loss results on sample C-338-5414A at three different temperatures. Figure 4 shows the continuous flow measurement results on sample C-338-5293 for up to 20 days. Because the C-338 samples had been stored for a long time prior to this experiment, no significant variations in hydrocarbon gas concentrations with time were recorded. The diffusion coefficient calculated from the microbalance experiments for sample C-338-5542 is in the order of 6×10^{-7} cm^2/sec, which agrees well with diffusion coefficients measured on other shale samples.

Task 3. Chemical Characterization Data

Chemical analysis results for carbon, hydrogen, and nitrogen (C-H-N) on C-338 samples are given in Table 5. Carbon values vary between 1.0 and 6.2 percent, whereas the hydrogen values range between 0.4 and 0.6 percent by weight of shale. Figures 5 and 6 illustrate carbon and hydrogen distribution in shales as a function of depth. There is an excellent correlation between the carbon and hydrocarbon gas distributions as a function of depth as illustrated in Figures 2 and 5. Both figures exhibit two regions where carbon and hydrocarbon gas contents vary with depth in a similar manner. Hydrogen contents, however, as shown in Figure 6, do not vary much with shale depth. Figure 7 shows H/C atomic ratio as a function of depth.

Figures 8 and 9 illustrate the variation in hydrocarbon gas contents with carbon and hydrogen, respectively. Hydrocarbon gas contents show an increase with increasing carbon and hydrogen contents.

Task 4. Summary of Physical Characterization Data

From among the physical characterization results, density, porosity (calculated from the density data), and surface area data are reported in Table 6. Table 7 summarizes the statistical parameters of the physical characterization data. Mercury intrusion porosity values are presented in Table 8, and also in Appendix A, in the form of tables and figures.

Figures 10 through 12 demonstrate one-to-one relationships between HC gas, carbon, hydrogen, and bulk densities. Natural gas contents vary inversely with the bulk densities as illustrated in Figure 10. Likewise, both carbon and hydrogen contents are inversely proportional to bulk density of the shales as demonstrated in Figures 11 and 12, respectively.

Gas permeabilities on a large number of C-338 samples were run in directions both parallel and vertical to bedding planes. Values found were very low to negligible permeabilities confirming the tight nature of these shale formations. The permeability values found are shown in Table 9. As the values in Table 9 indicate, shales are tight in both directions (parallel and vertical to bedding plane). This observation is contrary to the intuitive expectations that the shales might possibly be somewhat permeable in the direction parallel to bedding planes.

Task 5. Shale Lithology

Three of the four samples examined by the petrographic microscope showed illite as a major constituent, quartz in medium to high contents, and abundant pyrite. The fourth sample was highly stained, the opacity of much of the powder sample making mineral identification and quantity estimation impossible. One of the samples, showing by analysis little Ca or Mg, was noted to have a significant carbonate mineral content in the powder sample examined, and conversely no carbonate was seen in another sample whose analysis of the fractured surface of a specimen showed a significant Ca content. The analysis of the highly stained sample was very similar to the other samples that contained no Ca. Table 10 summarizes the EDAX analysis of four C-338 samples. X-ray diffraction analysis was performed on a number of samples. Semiquantitative results are summarized in Table 11. Almost all samples contain illite as the only clay mineral and in lesser quantities than other wells. No other clay minerals (kaolin and chlorite) are found. Quartz contents are moderate compared to other wells, but quartz is still the major single mineral as is the case with all the wells studied. Several carbonate minerals (e.g., nahcolite, shortite, siderite) are present in detectable quantities. Not much pyrite is found.

Figures 13 through 16 are SEM microphotographs of 4 C-338 samples.

Task 6. Data Interpretation and Correlation

The Automatic Interaction Detection (A.I.D.) program was run on the samples from this well in spite of the fact that with such a small number of samples (37), the statistical reliability of the results would be low. In addition to this, the wire log data available for this well were not very extensive and included only bulk density, porosity, gamma ray, micro laterolog, and conductivity.

Figure 17 shows the way the data for hydrocarbon gas contents are split based on laboratory and wire log data. Three splits are made and they show normal behavior with high surface area and low density both predicting high gas values. The use of these variables as predictors explains 63% of the variability in the criterion (hydrocarbon gas content). While this is not a particularly outstanding correlation, it is fairly typical of the results on previous wells.

When the laboratory data are disregarded (Figure 18), porosity, color, and depth are selected as the best predictors. The results show high porosity and deeper sample depths are associated with high gas contents. The shale color is also used as a splitting variable, but the results are slightly confusing in that they indicate that colors N1 and N4 indicate the presence of more gas than colors N2, N3, N5, and 5Y4/1. In another analysis with gas/unit volume of shale as the criterion and the wire log data as predictor variables, the overall results indicate that 50-55% variability is explained with the micro-laterolog being the best predictor.

Figures 19 and 20 show results of the A.I.D. runs with open porosity as the criterion variable. The most important observations from these analyses are that conductivity and gamma ray data show some promise as predictors and that there is a relationship between total carbon and porosity.

In general, the results of these A.I.D. runs are particularly valuable at the first split. The small data base requires changes in the program in order to increase the predicting efficiency of second and third splits. Splits beyond the first one, however, are still helpful in pointing out the trends with respect to additional variables.

TABLE 1. WELL DATA FOR C-338

LOCATION: WISE COUNTY, VA

ALTITUDE: 2395 FEET

COORDINATES: 37.00 (DEGREES.MINUTES) LATITUDE
82.41 (DEGREES.MINUTES) LONGITUDE

CORING BEGAN AT 4870 FEET AND STOPPED AT 5475 FEET. IT TOOK 11 BARRELS TO COMPLETE.

SAMPLES WERE RETURNED TO BATTELLE ON 5/ 3/77.

THERE WERE 40 SAMPLES COLLECTED FOR BATTELLE AND 41 SAMPLES COLLECTED FOR OTHERS.

RUN INFORMATION FROM WELL C-338

RUN NO. 1 CORING BEGAN AT 4870 FEET AND CORING STOPPED AT 4928 FEET. THE AVERAGE CORING RATE IS 7.33 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 4.00 HOURS

RUN NO. 2 CORING BEGAN AT 4928 FEET AND CORING STOPPED AT 4986 FEET. THE AVERAGE CORING RATE IS 15.05 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 3.62 HOURS

RUN NO. 3 CORING BEGAN AT 5210 FEET AND CORING STOPPED AT 5220 FEET. THE AVERAGE CORING RATE IS 51.50 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 4.42 HOURS

RUN NO. 4 CORING BEGAN AT 5220 FEET AND CORING STOPPED AT 5251 FEET. THE AVERAGE CORING RATE IS 13.84 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 4.08 HOURS

RUN NO. 5 CORING BEGAN AT 5251 FEET AND CORING STOPPED AT 5310 FEET. THE AVERAGE CORING RATE IS 10.32 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 3.47 HOURS

RUN NO. 6 CORING BEGAN AT 5310 FEET AND CORING STOPPED AT 5345 FEET. THE AVERAGE CORING RATE IS 8.26 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 3.18 HOURS

TABLE 1. (Continued)

RUN INFORMATION FROM WELL CONTINUED C-338

RUN NO. 7 CORING BEGAN AT 5345 FEET AND CORING STOPPED AT 5360 FEET. THE AVERAGE CORING RATE IS 8.00 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 3.28 HOURS

RUN NO. 8 CORING BEGAN AT 5360 FEET AND CORING STOPPED AT 5392 FEET. THE AVERAGE CORING RATE IS 10.25 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 3.43 HOURS

RUN NO. 9 CORING BEGAN AT 5392 FEET AND CORING STOPPED AT 5445 FEET. THE AVERAGE CORING RATE IS 4.56 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 4.33 HOURS

RUN NO. 10 CORING BEGAN AT 5445 FEET AND CORING STOPPED AT 5475 FEET. THE AVERAGE CORING RATE IS 9.27 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 2.50 HOURS

RUN NO. 11 CORING BEGAN AT 5684 FEET AND CORING STOPPED AT 5690 FEET. THE AVERAGE CORING RATE IS 46.15 MINUTES PER FOOT. THE SAMPLES WERE ON THE SURFACE IN 3.08 HOURS

TABLE 2. FIELD SAMPLING DATA FOR WELL C338

SAMPLE ID.	COLOR	ON SURFACE TIME	BARREL NO	SEQ NO.
C338-4872.	N1	2.03	1	1
C338-4882.	N1	2.12	1	2
C338-4892.	N1	2.35	1	3
C338-4902.	N1	2.42	1	4
C338-4912.	N1	2.50	1	5
C338-4922.	N1	2.77	1	6
C338-4930.	N1	1.90	2	7
C338-4940.	N1	2.08	2	8
C338-4950.	N4	2.38	2	9
C338-4960.	N4-N1	2.45	2	10
C338-4970.	N5	2.60	2	11
C338-4980.	N3	3.02	2	12
C338-5212.	N3-N1	.88	3	13
C338-5222.	N4	1.28	4	14
C338-5232.	N4	1.37	4	15
C338-5242.	N4	1.40	4	16
C338-5253.	N4	1.26	5	17
C338-5263.	N4	1.62	5	18
C338-5273.	N4	1.70	5	19
C338-5283.	N4	1.75	5	20
C338-5293.	N4	1.97	5	21
C338-5303.	N4	2.02	5	22
C338-5312.	N1	1.18	6	23
C338-5322.	N1	1.33	6	24
C338-5332.	N2	1.38	6	25
C338-5342.	N1	1.45	6	26
C338-5347.	N4-N1	1.10	7	27
C338-5357.	N1-N4	1.27	7	28
C338-5362.	N1	1.27	8	29
C338-5372.	N1	1.32	8	30
C338-5382.	N1	1.50	8	31
C338-5394.	5Y4/1	1.94	9	32
C338-5404.		2.00	9	33
C338-5414.	N1	2.23	9	34
C338-5424.	N2	2.27	9	35
C338-5434.	N25Y41	2.32	9	36
C338-5444.	N1	2.45	9	37
C338-5447.	N3	.62	10	38
C338-5457.	N1	.93	10	39
C338-5467.	N4	1.08	10	40

MEAN EXPOSURE TIME 1.80

STANDARD DEVIATION OF EXPOSURE TIME .58

TABLE 3. INITIAL GAS RELEASE DATA: WELL C-338

SAMPLE ID	PRESSURE TORR	FREE VOLUME CC	CORE VOLUME CC	OPEN POROSITY PCT.	GAS COMPOSITION, VOLUME PERCENT: METHANE	ETHANE	PROPANE	BUTANE	PENTANE	TOTAL HYDROC.	NITROGEN	OXYGEN	CARBON DIOXIDE	GAS RELEASED/ UNIT VOLUME OF SHALE	SEQ NO.
C338-4872.	2100.	820.	63[illegible].	1.04	64.00	6.74	.84	.24	0.00	71.82	26.55	.55	1.04	2.59	1
C338-4882.	2015.	928.	522.	1.69	61.70	6.30	.74	.15	0.00	68.89	27.2[illegible]	3.80	.11	3.25	2
C338-4892.	1967.	849.	601.	.84	64.50	6.70	.66	.08	0.00	72.14	25.10	2.80	.03	2.56	3
C338-4902.	1455.	923.	527.	1.73	63.40	7.63	.95	0.00	0.00	71.98	26.1[illegible]	1.93	.41	2.40	4
C338-4912.	2170.	881.	569.	1.77	65.90	6.99	.84	.10	0.00	73.83	25.10	.89	.22	3.27	5
C338-4922.	1795.	846.	604.	1.40	58.60	5.99	.74	.33	0.00	65.66	31.30	2.35	.71	2.17	6
C338-4930.	1460.	882.	568.	2.69	51.00	3.99	.53	0.00	0.00	55.52	37.30	6.70	.49	1.66	7
C338-4940.	1613.	900.	550.	1.51	52.20	5.57	.68	0.00	0.00	58.45	35.22	5.36	.98	2.03	8
C338-4950.	1220.	892.	558.	1.58	44.10	4.41	.59	.11	0.00	49.21	44.60	2.23	3.91	1.26	9
C338-4960.	1000.	860.	59[illegible].	2.29	41.81	3.87	.53	0.00	0.00	46.21	47.30	2.79	3.69	.89	10
C338-4970.	710.	931.	519.	.53	2.73	0.00	0.00	0.00	0.00	2.73	76.79	19.99	.51	.05	11
C338-4980.	760.	913.	537.	1.61	10.80	16.76	.11	0.00	0.00	27.67	63.50	.63	8.30	.47	12
C338-5212.	1050.	855.	595.	5.27	38.70	3.33	3.77	0.00	0.00	45.60	53.24	1.27	3.06	.91	13
C338-5222.	1075.	823.	627.	2.83	39.66	3.87	.38	0.00	0.00	43.91	52.28	1.06	2.75	.82	14
C338-5232.	1975.	512.	938.	2.77	65.23	4.15	.30	0.00	0.00	69.68	29.62	.41	.88	.99	15
C338-5242.	1475.	888.	562.	2.13	58.01	4.62	.38	0.00	0.00	63.61	34.2[illegible]	1.21	1.58	1.93	16
C338-5253.	1558.	876.	574.	1.15	55.40	8.00	.65	0.00	0.00	64.05	34.28	.47	1.23	2.00	17
C338-5263.	1640.	695.	755.	1.31	57.21	5.27	.61	0.00	0.00	63.09	35.45	.48	.99	1.25	18
C338-5273.	750.	1450.	[illegible]	2.06	58.12	8.25	1.10	0.00	0.00	67.47	30.80	.42	1.25	R	19
C338-5283.	800.	744.	706.	2.69	67.81	9.67	.84	0.00	0.00	77.72	20.81	.34	.67	.86	20
C338-5293.	925.	769.	681.	2.14	71.81	9.30	.86	0.00	0.00	81.97	17.22	.26	.55	1.13	21
C338-5303.	2900.	493.	957.	1.18	77.59	4.78	.44	0.00	0.00	82.72	16.70	.33	.26	1.62	22
C338-5312.	1250.	1067.	383.	2.15	47.39	6.37	.54	0.00	0.00	54.30	42.62	.60	2.53	2.49	23
C338-5322.	177[illegible].	826.	624.	2.55	61.79	5.25	.43	.09	0.00	67.47	31.10	.43	.98	2.08	24
C338-5332.	870.	912.	538.	2.37	21.60	1.50	.[illegible]7	0.00	0.00	23.17	63.60	11.90	1.35	.45	25
C338-5342.	1225.	797.	653.	.49	72.10	6.80	.61	0.0[illegible]	0.00	79.51	19.80	.59	.13	1.56	26
C338-5347.	1740.	645.	805.	1.16	60.[illegible]	4.56	.43	.09	0.00	65.08	32.80	.98	1.21	1.19	27
C338-5357.	1150.	712.	738.	.98	70.50	6.15	.51	0.00	0.00	77.16	21.30	.34	1.29	1.13	28
C338-5362.	1150.	899.	551.	.28	73.90	7.91	.63	.06	0.00	62.50	16.70	.33	.53	2.03	29
C338-5372.	975.	812.	638.	.72	78.30	8.50	.70	0.00	0.00	87.56	11.3[illegible]	.57	.22	1.43	30
C338-5382.	1000.	906.	544.	.73	66.60	6.70	.61	0.00	0.00	73.91	23.10	2.80	.20	1.62	31
C338-5394.	1075.	722.	728.	2.11	35.65	2.92	.46	0.00	0.00	39.03	53.19	6.37	1.41	.55	32
C338-5404.	850.	1010.	440.	1.43	51.03	6.35	.75	.07	0.00	58.20	36.55	4.96	.29	1.49	33
C338-5414.	1490.	972.	478.	.69	62.90	6.10	.47	0.00	0.00	69.47	26.47	4.01	.78	2.77	34
C338-5424.	2600.	807.	643.	2.36	69.85	5.71	.41	0.00	0.00	75.97	21.55	2.38	.09	3.26	35
C338-5434.	1125.	796.	654.	1.11	55.20	5.80	.68	0.00	0.00	61.68	34.50	3.60	.25	1.11	36
C338-5444.	1125.	950.	50[illegible].	.72	71.37	7.50	.55	0.00	0.00	79.35	18.80	1.67	.08	2.23	37
C338-5447.	2337.	803.	647.	.74	68.90	6.34	.40	0.00	0.00	75.64	23.40	.46	.48	2.89	38
C338-5457.	975.	915.	535.	.64	56.30	5.10	.36	0.00	0.00	61.76	32.00	6.20	.08	1.36	39
C338-5467.	1075.	767.	683.	1.09	80.40	7.50	.55	0.00	0.00	88.45	11.10	.46	.41	1.41	40

TABLE 4. STATISTICAL ANALYSES OF OFF GAS DATA

WELL C338

	MEAN	STANDARD DEVIATION	VARIENCE	COEFFICIENT OF DEVIATION	95 PCT. CONFIDENCE INTERVAL LOWER LIMIT	95 PCT. CONFIDENCE INTERVAL UPPER LIMIT	NO OF SAMPLES
ETHANE, PERCENT	6.066	2.61	6.80	.43	5.233	6.900	40
PROPANE, PERCENT	.647	.56	.31	.86	.470	.825	40
BUTANE, PERCENT	.033	.07	.01	2.16	.010	.056	40
PENTANE, PERCENT	0.000	0.00	0.00	I	0.000	0.000	40
TOTAL HYDROCARBONS, PCT	63.590	18.01	324.41	.28	57.835	69.346	40
NITROGEN, PERCENT	32.748	14.75	217.48	.45	28.036	37.461	40
OXYGEN, PERCENT 1	2.623	3.73	13.91	1.42	1.431	3.815	40
CARBON DIOXIDE, PERCENT	1.146	1.51	2.29	1.32	.663	1.630	40
GAS VOLUME/SHALE VOLUME	1.166	1.06	1.12	.91	-4.590 ? .98	1.504	40

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TABLE 5. CHEMICAL CHARACTERIZATION DATA, 3/78

SAMPLE ID	TOTAL, PERCENT CARBON	HYDROGEN	NITROGEN	LOW TEMPERATURE ASH, % 200 C	100 C	CARD CODE	SEQ NO.
C338-4872.	4.0	.4	.1			5	1
C338-4882.	6.2	.6	.2			5	2
C338-4902.	5.9	.6	.2			5	3
C338-4912.	5.2	.5	.2			5	4
C338-4912.	5.2	.5	.2			5	5
C338-4922.	3.2	.4	.1			5	6
C338-4930.	2.3	.4	.1			5	7
C338-4940.	2.8	.8	.1			5	8
C338-4950.	3.1	.4	.1			5	9
C338-4960.	1.3	.4	.1			5	10
C338-4970.	3.4	.3	.1			5	11
C338-4980.	1.2	.5	.1			5	12
C338-5212.	1.1	.5	.1			5	13
C338-5222.	1.2	.5	.1			5	14
C338-5242.	1.4	.5	.1			5	16
C338-5253.	2.5	.5	.1			5	17
C338-5263.	1.1	.5	.1			5	18
C338-5273.	1.7	.5	.1			5	19
C338-5283.	1.7	.5	.1			5	20
C338-5293.	2.5	.5	.1			5	21
C338-5303.	2.1	.5	.1			5	22
C338-5312.	2.5	.5	.1			5	23
C338-5322.	1.8	.5	.2			5	24
C338-5332.	1.0	.5	.1			5	25
C338-5342.	3.5	.6	.2			5	26
C338-5347.	1.7	.5	.1			5	27
C338-5357.	1.9	.4	.1			5	28
C338-5362.	6.2	.6	.2			5	29
C338-5372.	4.7	.5	.2			5	30
C338-5382.	4.0	.5	.2			5	31
C338-5396.	2.6	.4	.1			5	32
C338-5424.	5.0	.5	.2			5	35
C338-5434.	2.4	.5	.1			5	36
C338-5444.	6.2	.6	.2			5	37
C338-5447.	5.1	.6	.2			5	38
C338-5457.	4.9	.6	.2			5	39
C338-5467.	4.8	.6	.2			5	40

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TABLE 6. SUMMARY OF PHYSICAL CHARACTERIZATION DATA FOR WELL C-338

	BULK DENSTY G/CC	OPEN PORSTY PCT	CLOSED PORSTY PCT	TOTAL POROSITY PCT	SURFACE AREA M2/G	SEQ
C338-4872.	2.610	1.043	0.000	1.043	11.520	1
C338-4882.	2.484	1.689	6.313	8.002	11.940	2
C338-4892.	2.555	.844	3.071	3.914	8.350	3
C338-4902.	2.490	1.732	1.394	3.126	13.190	4
C338-4912.	2.523	1.773	3.778	5.552	8.900	5
C338-4922.	2.615	1.396	3.077	4.473	8.980	6
C338-4930.	2.625	2.089	0.000	2.089	6.160	7
C338-4940.	2.618	1.513	0.000	1.513	9.420	8
C338-4950.	2.694	1.578	3.360	4.938	5.930	9
C338-4960.	2.844	2.286	.474	2.760	3.130	10
C338-4970.	2.824	.530	.227	.757	2.530	11
C338-4980.	2.722	1.608	0.000	1.608	2.230	12
C338-5212.	2.808	5.267	0.000	5.267	3.330	13
C338-5222.	2.745	2.833	0.000	2.833	4.280	14
C338-5232.	2.696	2.770	2.432	5.203	3.520	15
C338-5242.	2.895	2.134	.595	2.729	4.540	16
C338-5253.	2.726	1.153	2.735	3.889	7.310	17
C338-5263.	2.776	1.307	1.099	2.406	3.230	18
C338-5273.	2.694	2.058	1.724	3.782	2.530	19
C338-5283.	2.713	2.086	0.000	2.086	5.540	20
C338-5293.	2.662	2.142	0.000	2.142	5.560	21
C338-5303.	2.667	1.182	1.006	2.188	4.800	22
C338-5312.A	2.666	2.154	0.000	2.154	8.310	23
C338-5322.	2.679	2.553	5.407	7.959	6.560	24
C338-5332.	2.761	2.365	5.031	7.396	2.760	25
C338-5342.	2.672	.398	0.000	.398	7.740	26
C338-5347.	2.756	1.159	1.438	2.597	7.180	27
C338-5357.	2.733	.979	2.357	3.335	11.200	28
C338-5362.	2.568	.276	1.005	1.280	14.020	29
C338-5372.	2.590	.723	0.000	.723	16.690	30
C338-5382.	2.622	.732	5.346	6.078	11.900	31
C338-5394.	2.724	2.113	.403	2.515	3.890	32
C338-5404.	2.627	1.428	3.577	5.006	3.730	33
C338-5414.	2.551	.891	0.000	.891	21.520	34
C338-5424.	2.590	2.361	3.993	6.353	18.040	35
C338-5434.	2.695	1.113	.354	1.467	3.160	36
C338-5444.	2.548	.721	0.000	.721	24.010	37
C338-5447.	2.598	.741	1.298	2.039	15.760	38
C338-5457.	2.650	.642	0.000	.642	18.310	39
C338-5467.	2.567	1.094	.779	1.874	12.970	40

TABLE 7. STATISTISTICAL ANALYSES OF PHYSICAL CHARACTERIZATION DATA

WELL C-338

	MEAN	STANDARD DEVIATION	VARIENCE	COEFFICIENT OF DEVIATION	95 PCT. CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT	NO OF SAMPLES
BULK DENSITY, G/CC	2.664	.10	.01	.04	2.634	2.695	40
APPARENT DENSITY, G/CC	2.708	.11	.01	.04	2.673	2.743	40
TRUE DENSITY, G/CC	2.693	.14	.02	.05	2.648	2.739	40
OPEN POROSITY, PCT	1.586	.91	.82	.57	1.297	1.876	40
CLOSED POROSITY, PCT	1.557	1.84	3.37	1.18	.970	2.144	40
TOTAL POROSITY, PCT	3.143	2.09	4.36	.66	2.476	3.810	40
WEIGHT LOSS INITIAL, G/KG	9.473	3.06	9.38	.32	8.494	10.451	40
WEIGHT LOSS FINAL, G/KG	-.881	1.16	1.32	-1.31	0.000	-.613	40
TOTAL WEIGHT LOSS, G/KG	8.592	2.64	6.98	.31	7.747	9.436	40

TABLE 8. MERCURY INTRUSION POROSIMETER FOR WELL C-338

SEQUENCE NUMBER	SAMPLE ID	POROSITY, %
1	4872	3.82
2	4882	5.30
3	4892	6.10
5	4912	4.80
6	4922	4.80
7	4930	3.01
8	4940	4.24
9	4950	3.44
10	4960	4.24
11	4970	3.01
12	4980	4.24
13	5212	3.20
14	5222	4.50
15	5232	2.12
16	5242	3.71
17	5253	2.12
18	5263	4.80
19	5273	0.26
20	5283	2.65
21	5293	4.24
22	5303	4.10
23	5312.A	5.10
24	5322	3.71
25	5332	3.71
26	5342	2.65
27	5347	4.50
28	5357	3.20
29	5362	1.32
30	5372	3.44
31	5382	3.44
33	5404	3.44
34	5414	2.12
35	5424	5.03
36	5434	4.24
37	5444	4.24
38	5447	3.71
39	5457	3.71
40	5467	3.71

TABLE 9. PERMEABILITY VALUES OF C-338 SHALES IN MILLIDARCY

Sample I.D. #	Direction of Flow Relative to Bedding Planes	Permeabilities, md
C-338-5404	vertical	0
C-338-5414	ditto	5.6×10^{-7}
C-338-5424	"	0
C-338-5434	"	0
C-338-5444	"	0
C-338-5447	"	6.7×10^{-7}
C-338-5467	"	9.1×10^{-8}
C-338-4872	vertical	0
C-338-4882	horizontal	0
C-338-4912	vertical	0
C-338-4922	horizontal	1.12×10^{-6}
C-338-4950	ditto	0
C-338-4960	"	0
C-338-4970	"	0
C-338-5232	vertical	0
C-338-5283	ditto	0
C-338-5293	"	0
C-338-5303	"	0
C-338-5312	horizontal	6.7×10^{-7}
C-338-5322	vertical	0
C-338-5332	horizontal	0
C-338-5347	vertical	0
C-338-5357	ditto	0
C-338-5362	"	0
C-338-5372	"	0
C-338-5404	"	0
C-338-5414	"	5.6×10^{-7}
C-338-5424	"	0
C-338-5434	"	0
C-338-5444	"	0
C-338-5447	"	6.7×10^{-7}
C-338-5467	"	9.1×10^{-8}

TABLE 10. ENERGY-DISPERSIVE ANALYSIS OF SHALES

	Element Count Per 100 Counts												
Shale Sample	Na	K	Ca	Mg	Al	Si	Fe	S	Ti	P	Fe/S	K/Al	K/Si	Al/Si
C-338-4872	-	6.7	-	Tr	17.8	62.8	6.8	4.6	1.3	-	1.5	0.38	0.11	0.28
C-338-5242A	-	6.4	5.3	-	21.7	52.7	4.6	8.3	1.0	-	0.6	0.29	0.12	0.41
C-338-5362A	-	6.6	-	-	18.5	64.0	4.6	5.6	0.7	-	0.8	0.35	0.10	0.29
C-338-5467	-	9.4	-	Tr	18.2	61.0	7.0	3.2	1.2	-	2.2	0.51	0.15	0.30

TABLE 11. MINERALS OBSERVED BY XRD ANALYSIS ON RANDOM SHALE SAMPLES

Sample No.	Quartz	Illite	Kaolin	Pyrite	Nahcolite	Shortite	Siderite	Calcite	Mica	Others
C-338-4872	M	M	m	m	m	m	m	m	–	–
C-338-4892	M	–	–	m	–	m	d	m	–	–
C-338-4912	M	M	m	d	–	m	d	d	–	–
C-338-4922	M	–	–	d	d	d	–	m	–	–
C-338-4960	M	M	m	m	–	m	d	d	–	–
C-338-5232	M	d	d	m	d	m	d	d	–	–
C-338-5283	M	M	m	m	–	m	d	d	–	–
C-338-5322	M	m	m	m	m	m	d	m	–	–
C-338-5357	M	–	d	m	d	m	d	m	–	–
C-338-5362	M	–	d	m	–	m	d	m	–	–
C-338-5372	M	–	d	m	d	m	–	m	–	–
C-338-5714	M	–	d	m	m	m	–	m	–	–
C-338-5424	M	–	d	d	m	d	d	m	–	–
C-338-5444	M	m	d	m	m	m	–	m	–	–
C-338-5457	M	M	d	m	–	m	d	d	–	–

LEGEND

M – Major
m – Minor
d – Detectable

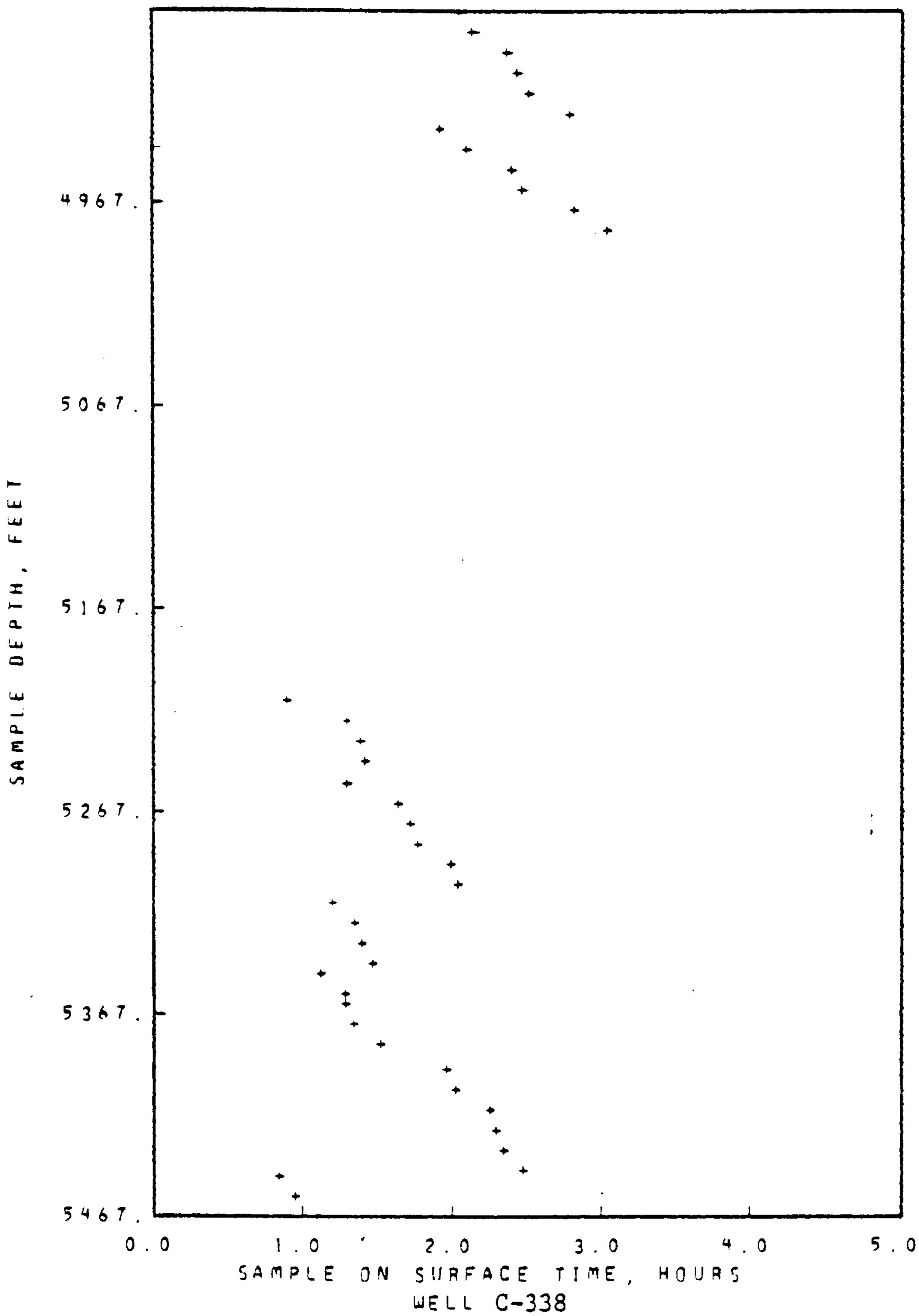


FIGURE 1. ON-SURFACE TIME FOR WELL C-338

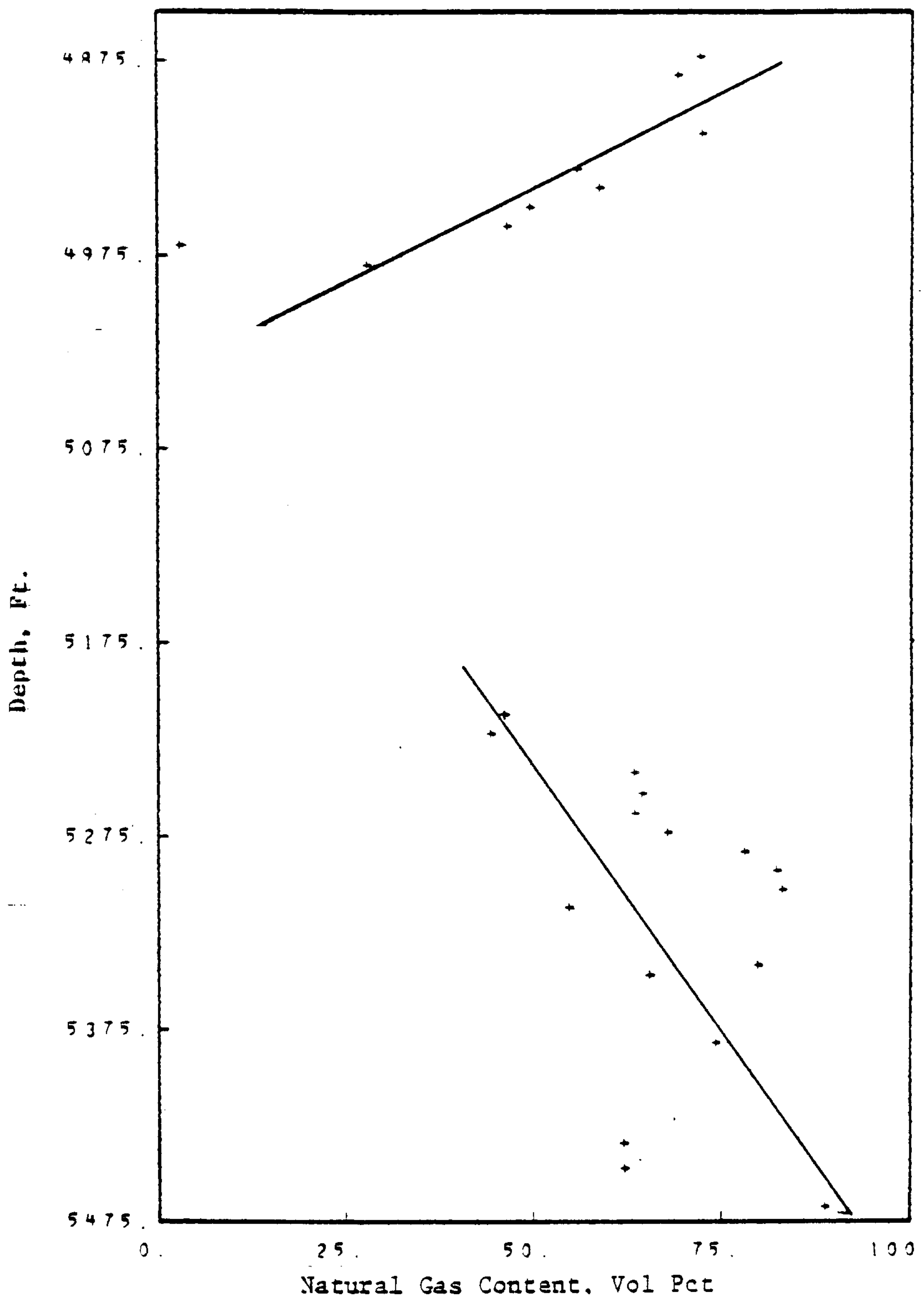


FIGURE 2. GAS CONTENT AS A FUNCTION OF SAMPLE DEPTH FOR WELL C-338

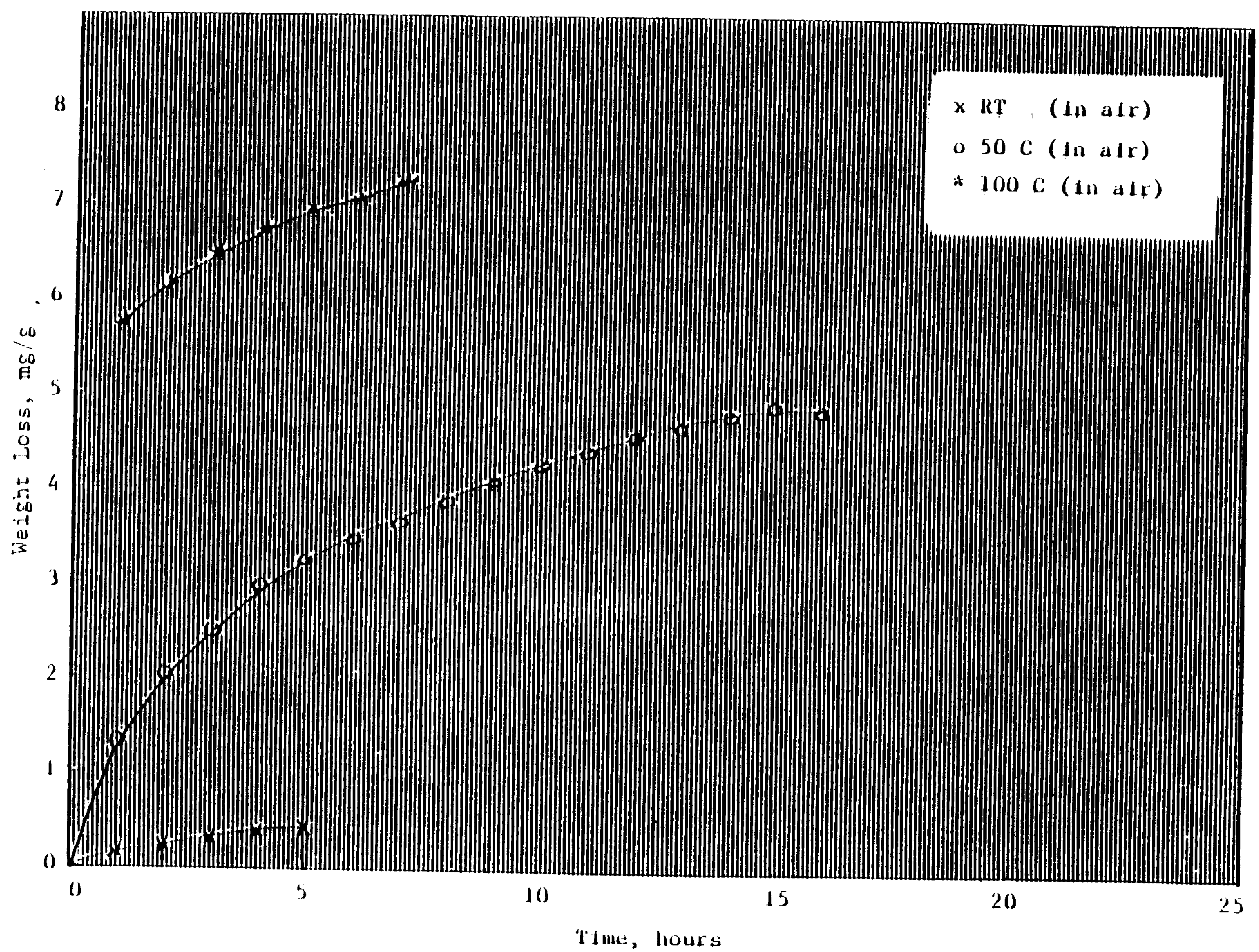


FIGURE 3. MICROBALANCE WEIGHT LOSS RATES FOR SHALE SAMPLE C-338-5414A

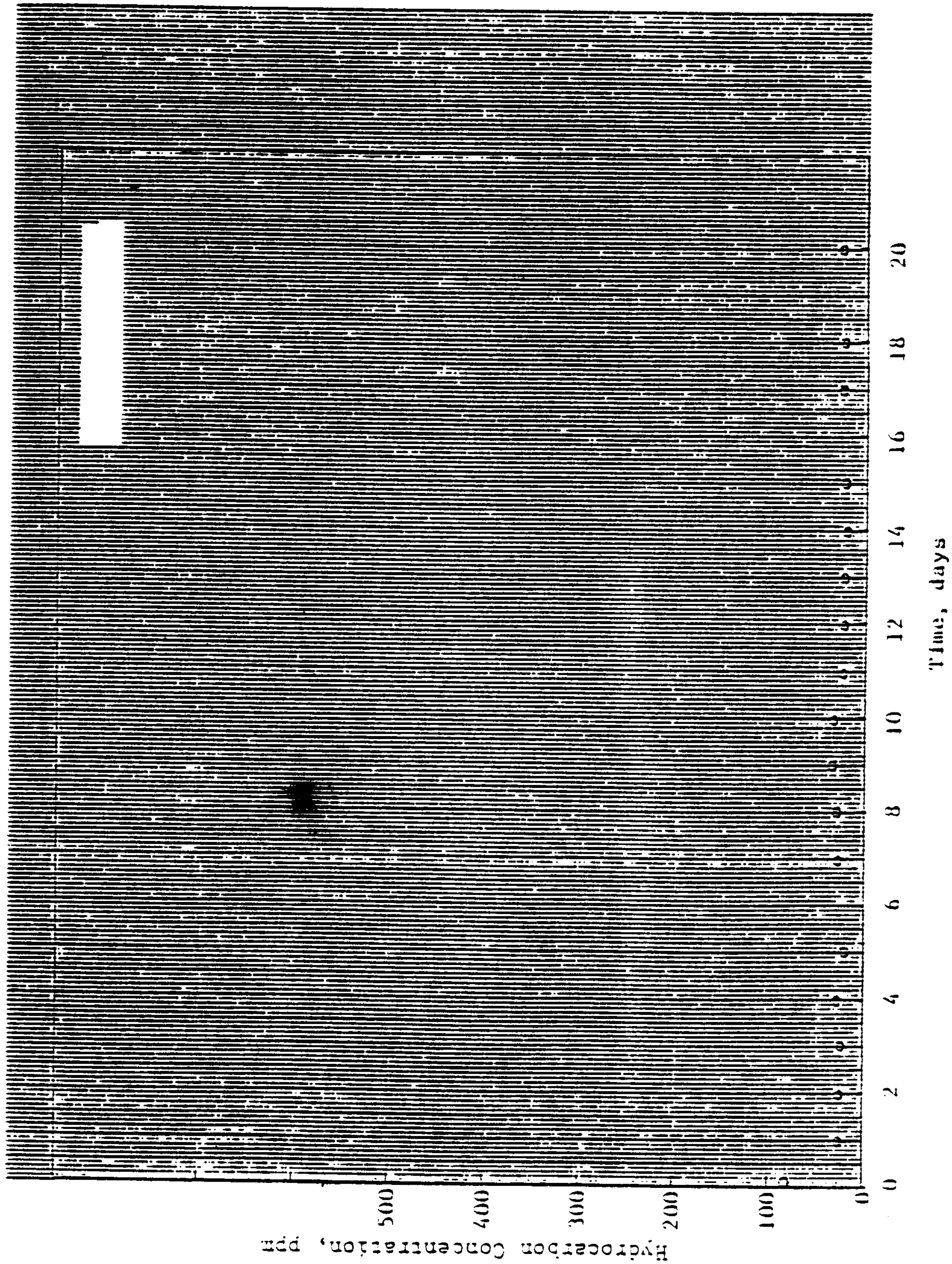


FIGURE 4. HYDROCARBON GAS RELEASE RATES IN SAMPLE C-338-5293

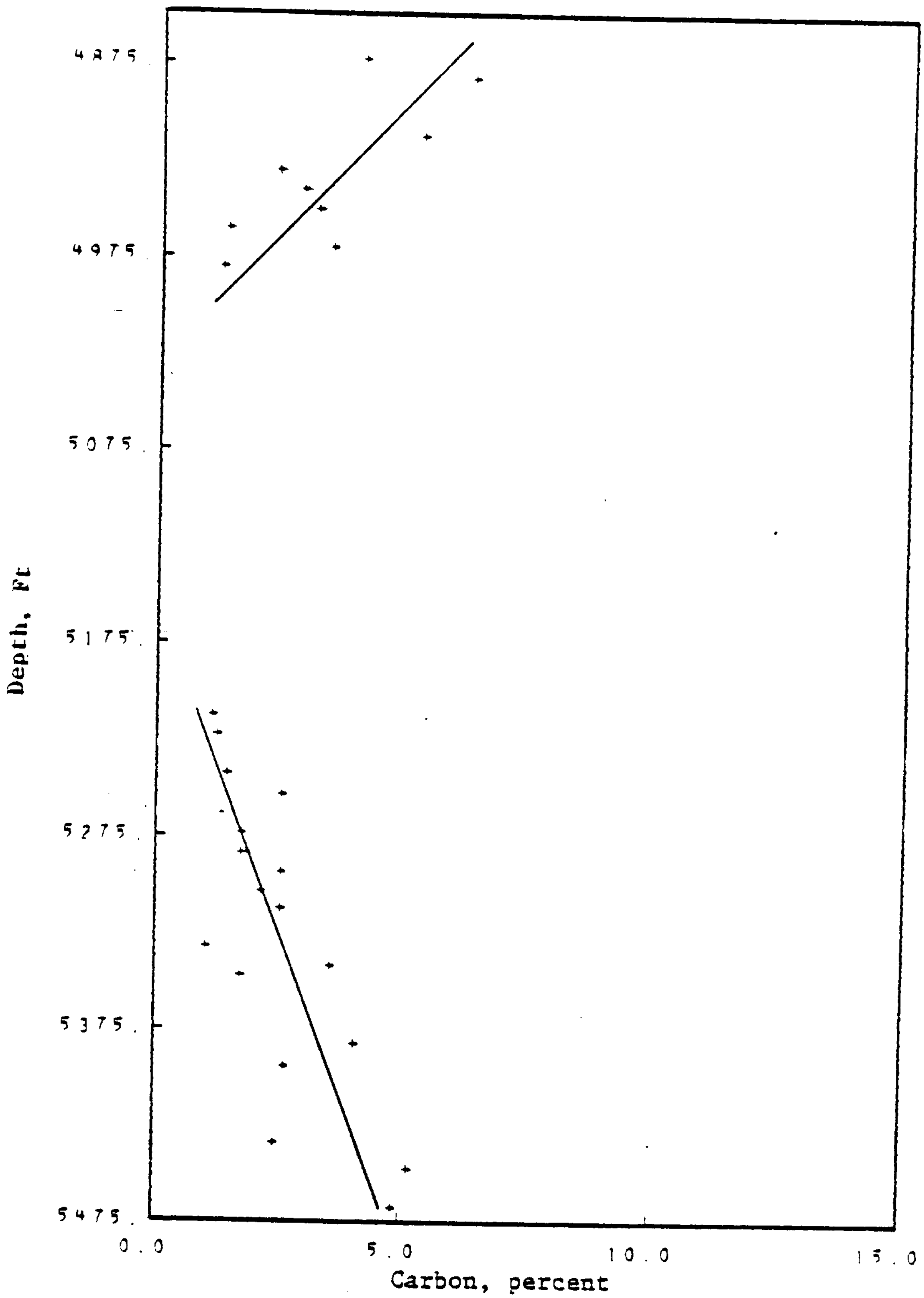


FIGURE 5. CARBON CONTENT AS A FUNCTION OF SAMPLE DEPTH FOR WELL C-338

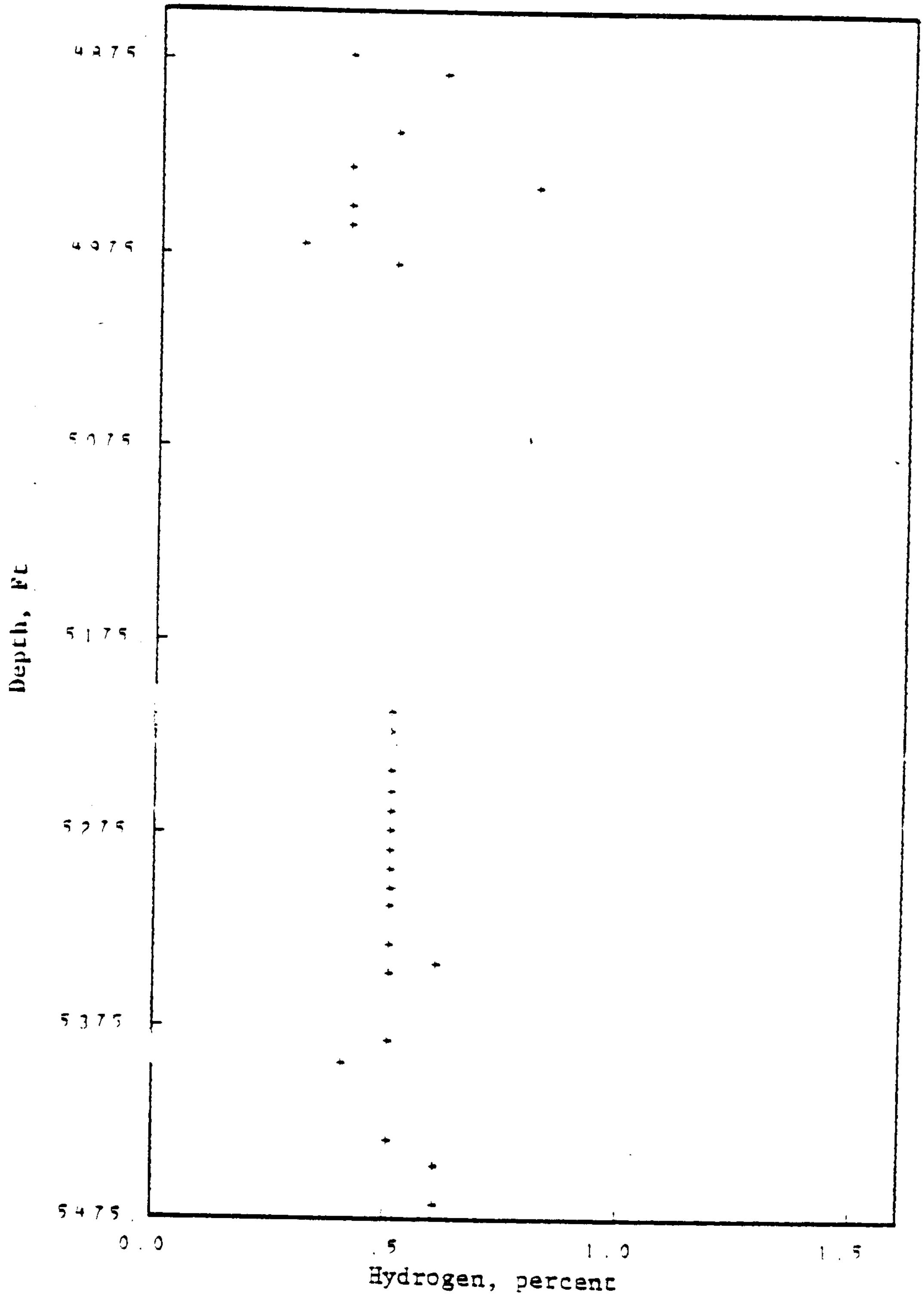


FIGURE 6. HYDROGEN CONTENT AS A FUNCTION OF SAMPLE DEPTH FOR WELL C-338

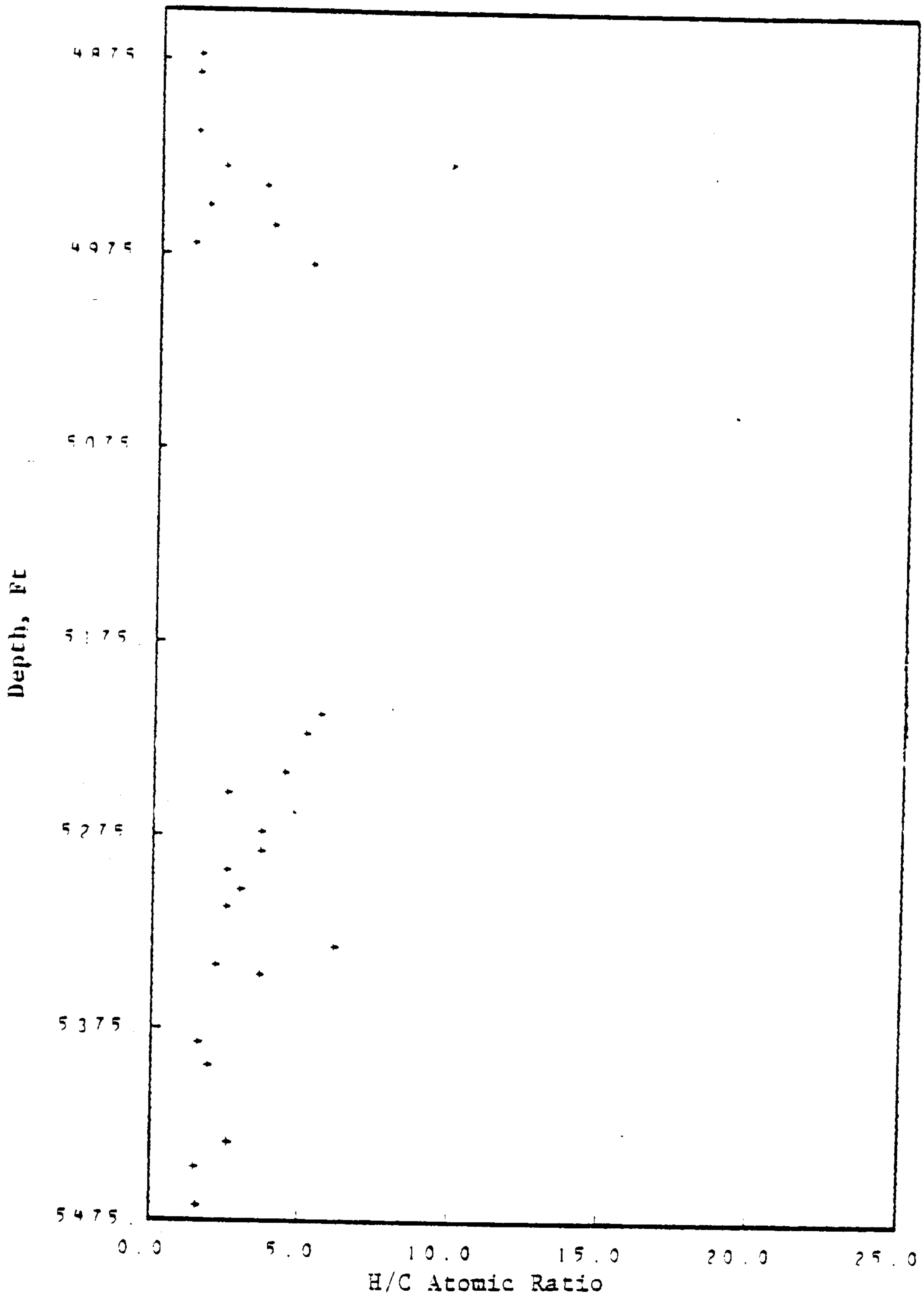


FIGURE 7. H/C ATOMIC RATIO AS A FUNCTION OF SAMPLE DEPTH FOR WELL C-338

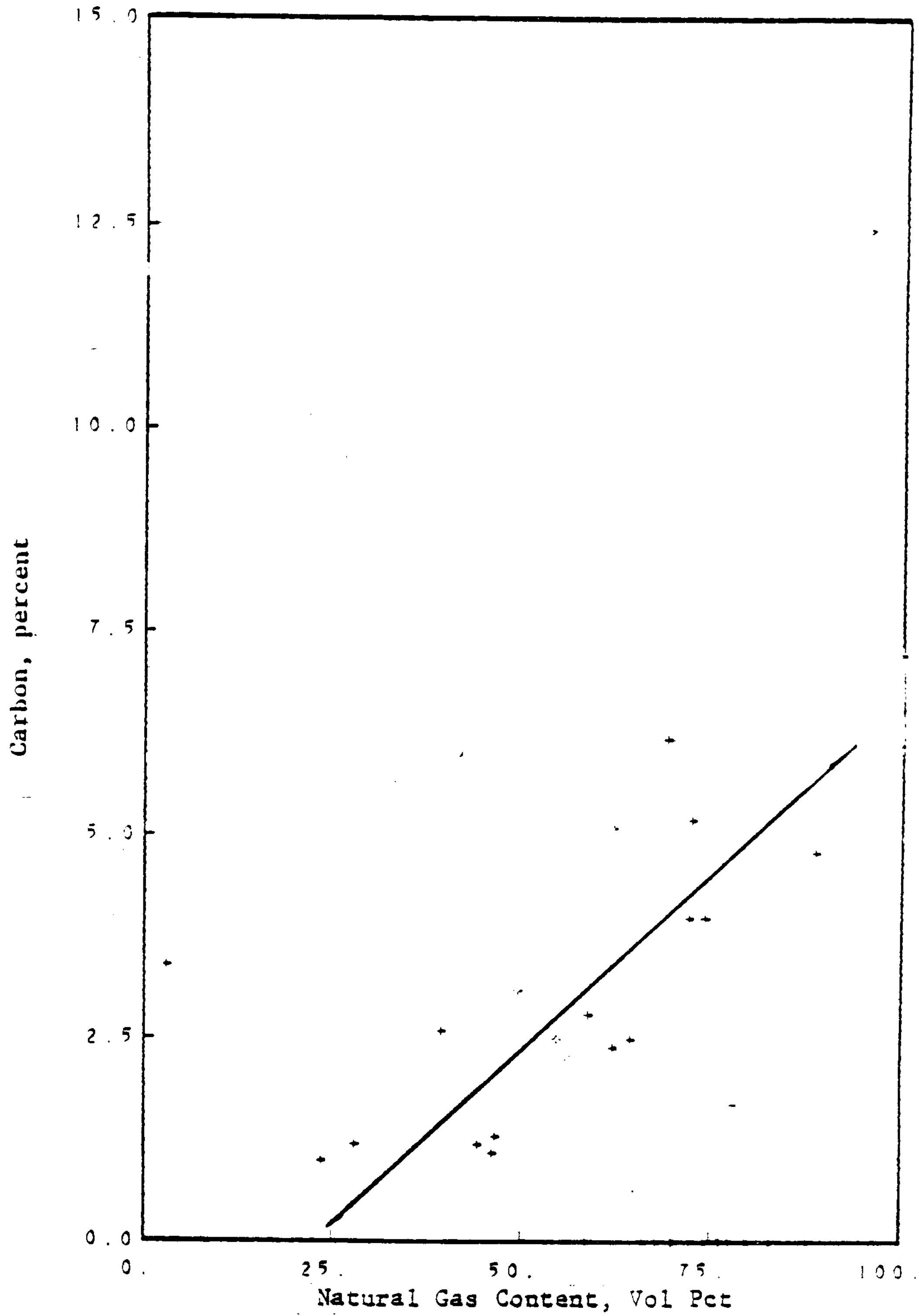


FIGURE 8. GAS CONTENT AS A FUNCTION OF CARBON CONTENT FOR WELL C-338

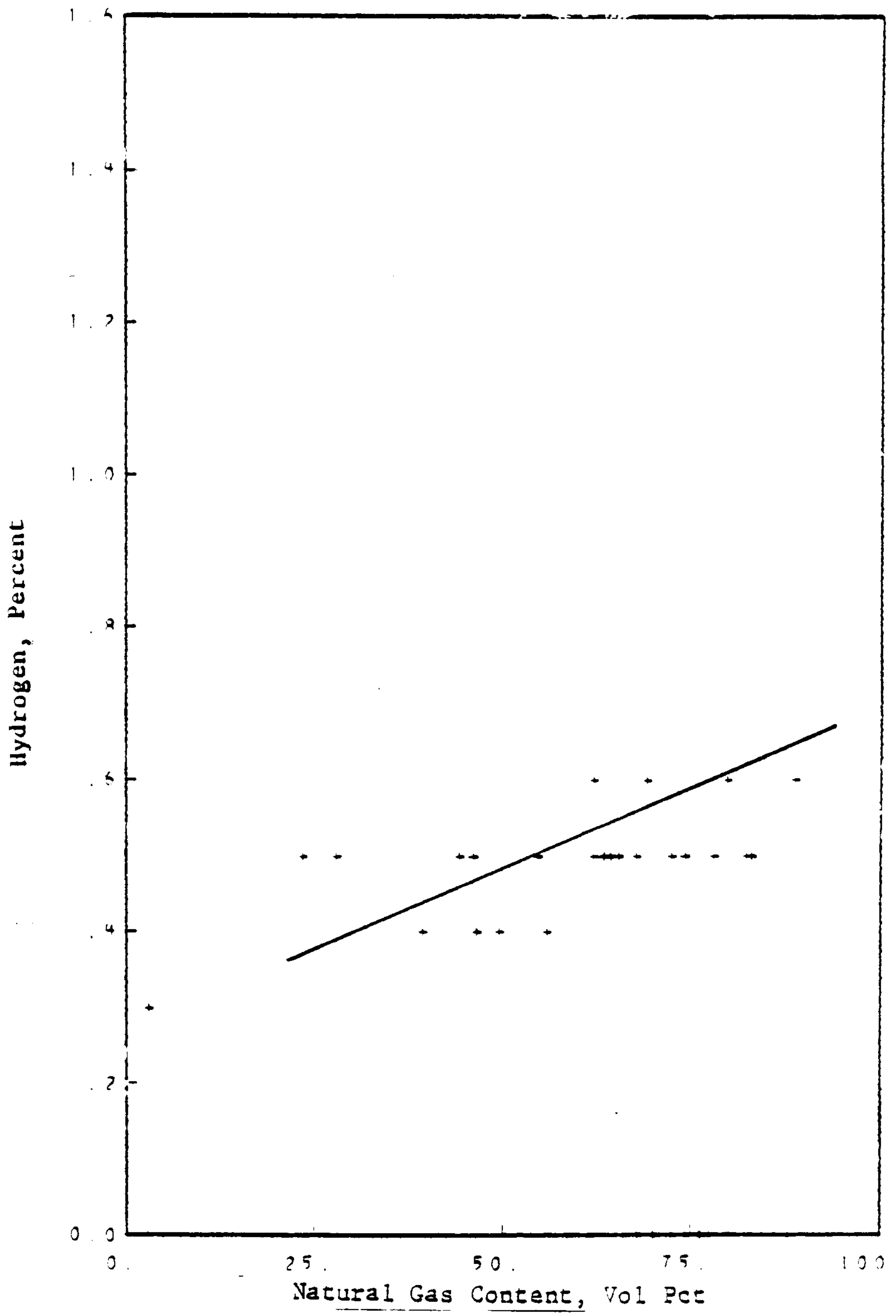


FIGURE 9. GAS CONTENT AS A FUNCTION OF HYDROGEN CONTENT FOR WELL C-388

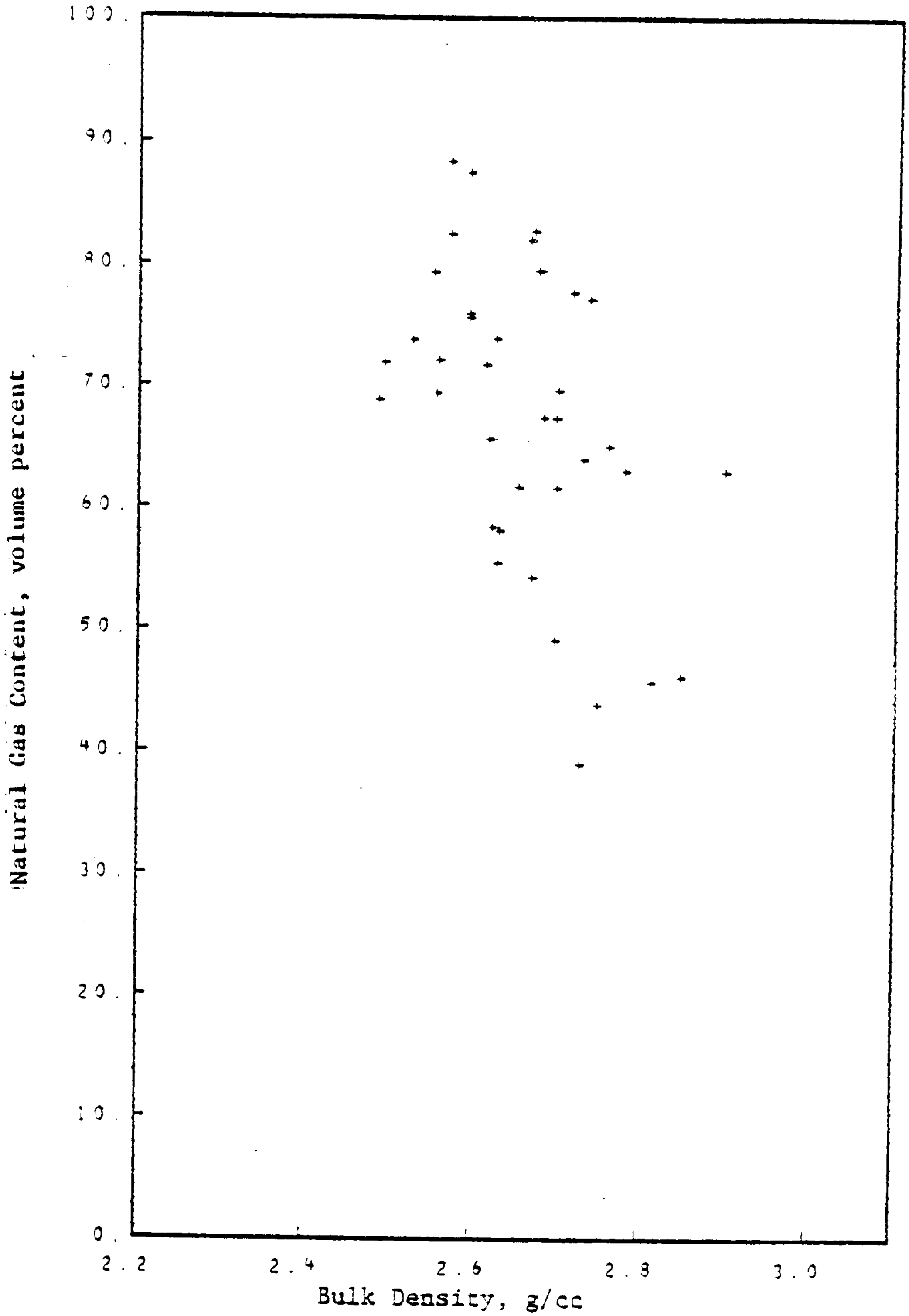


FIGURE 10. GAS CONTENT AS A FUNCTION OF BULK DENSITY FOR WELL C-338

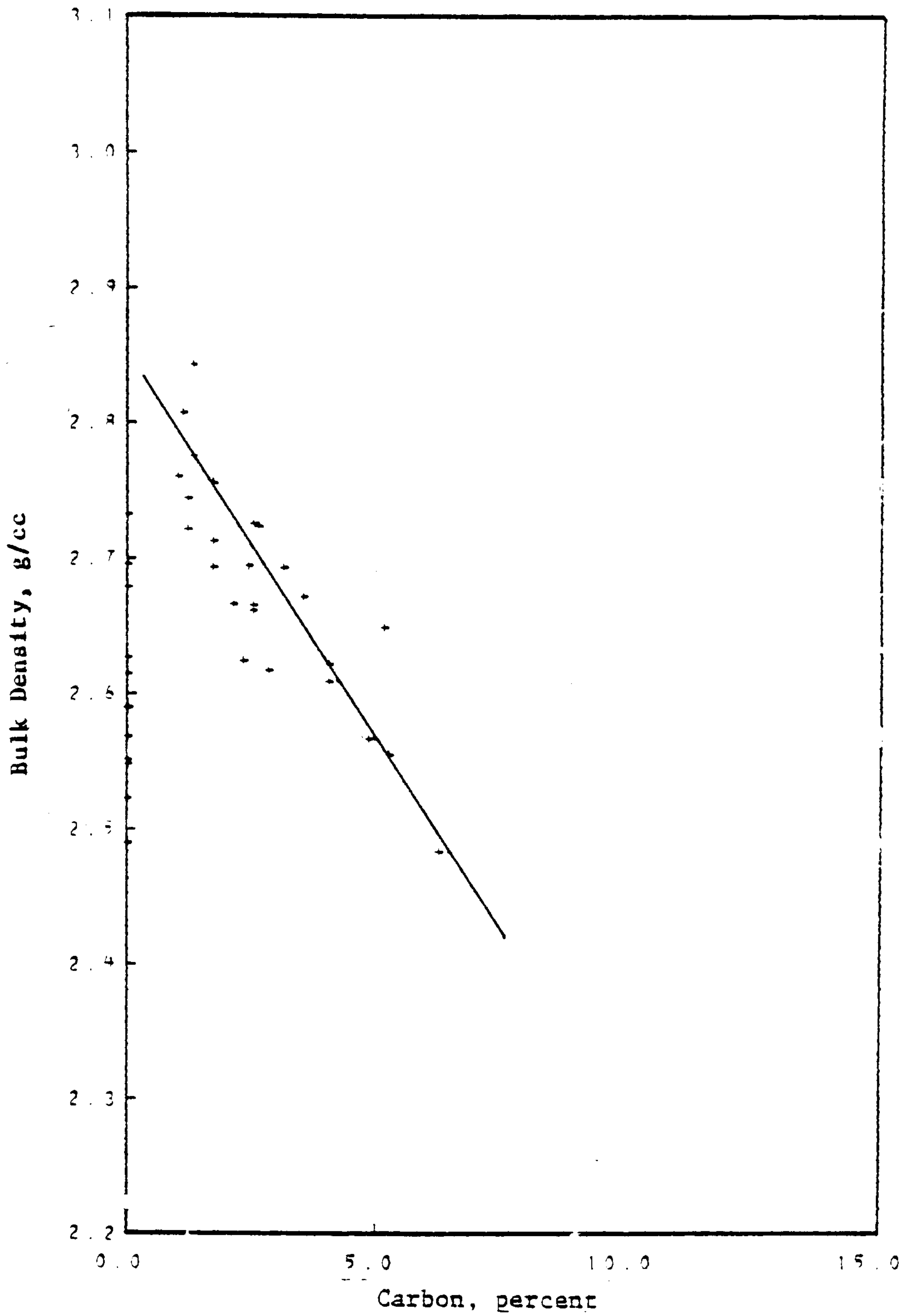


FIGURE 11. CARBON CONTENT AS A FUNCTION OF BULK DENSITY FOR WELL C-338

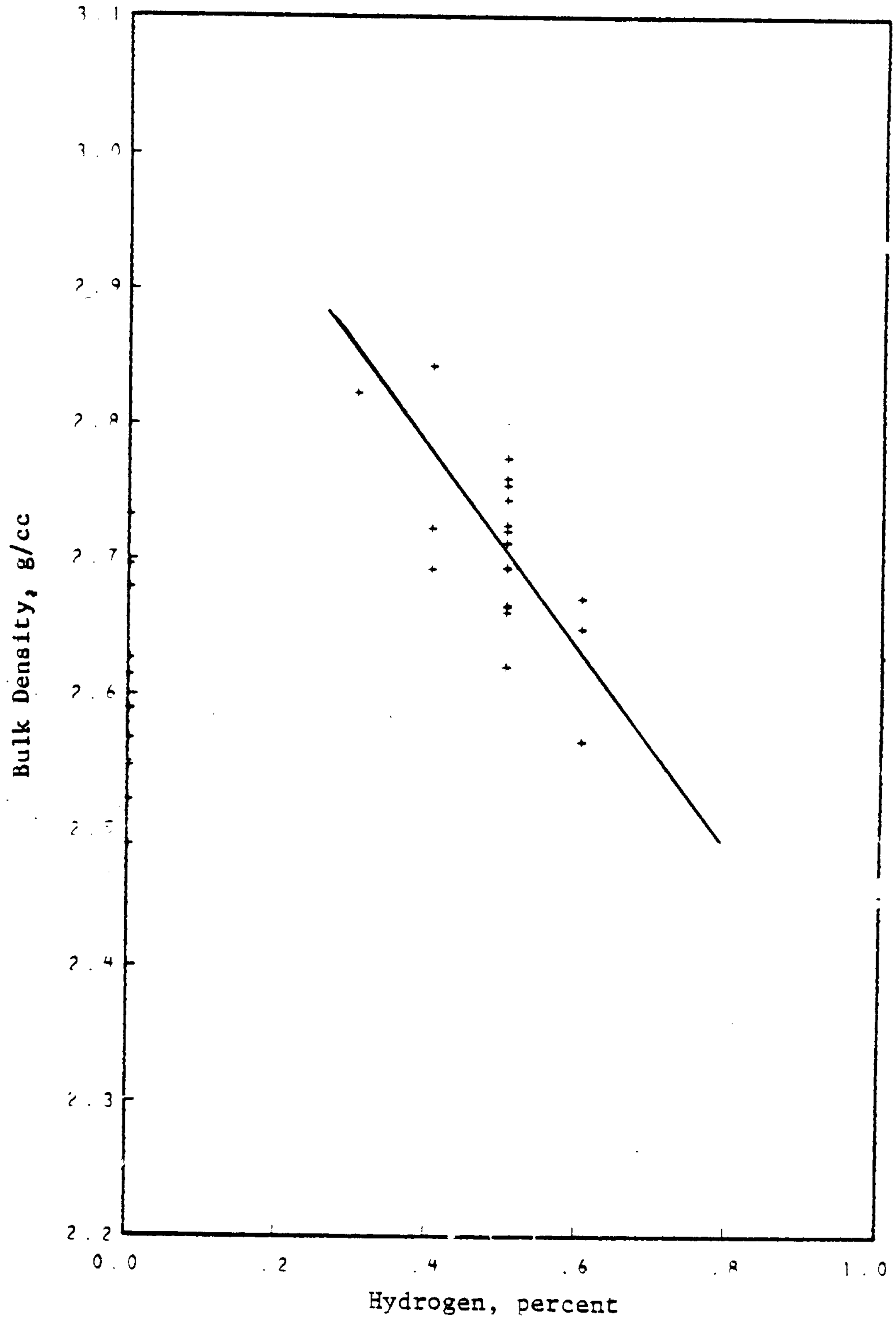
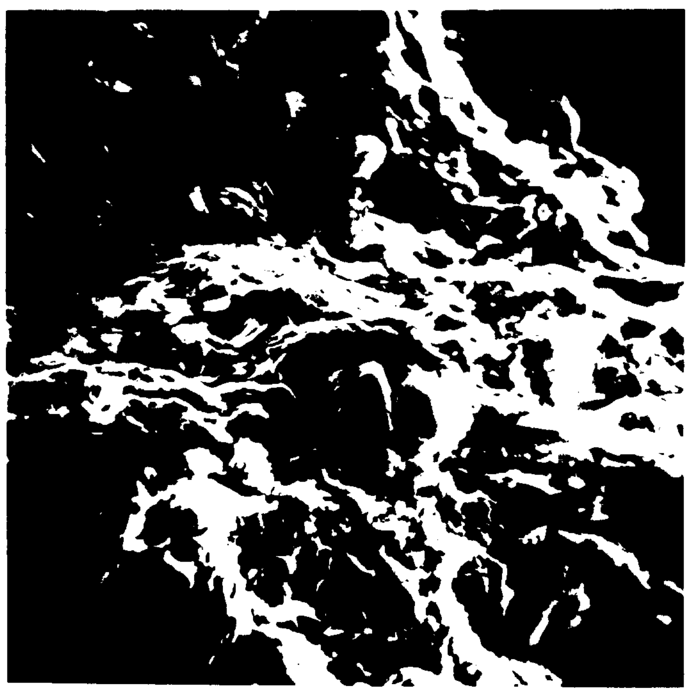
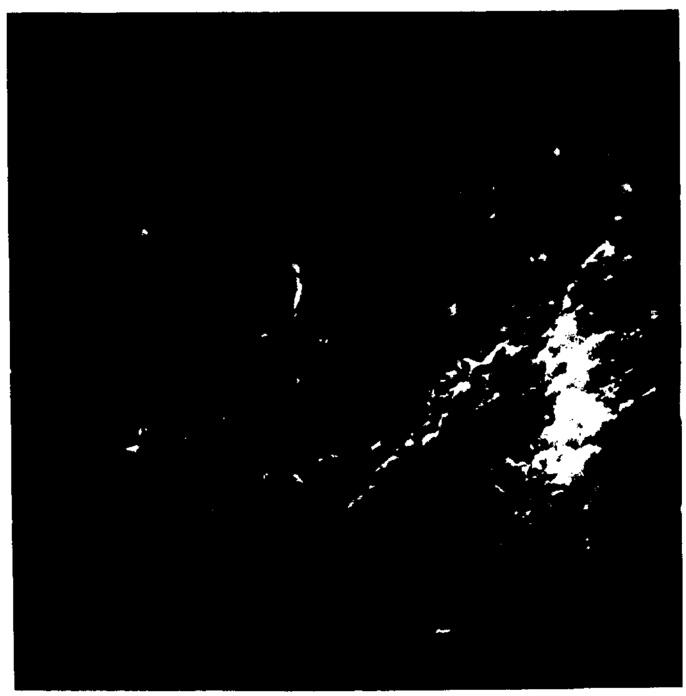


FIGURE 12. HYDROGEN CONTENT AS A FUNCTION OF BULK DENSITY FOR WELL C-338



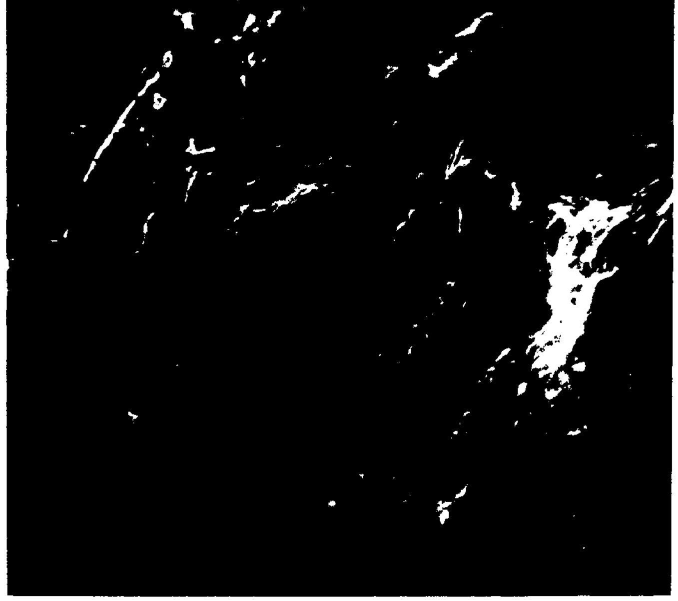
670X

FIGURE 13. SEM PHOTOMICROGRAPH OF SAMPLE C-338-4872



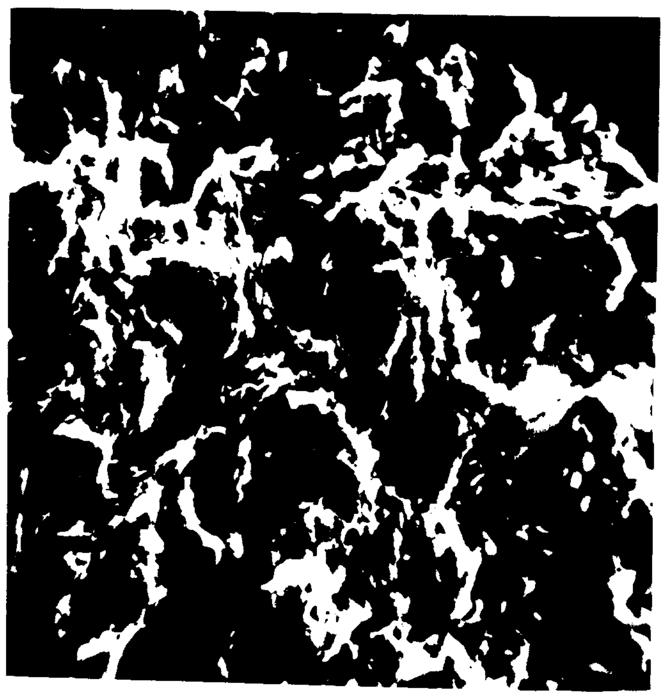
700X

FIGURE 14. SEM PHOTOMICROGRAPH OF SAMPLE C-338-5242



700X

FIGURE 15. SEM PHOTOMICROGRAPH OF SAMPLE C-338-5362



710X

FIGURE 16. SEM PHOTOMICROGRAPH OF SAMPLE C-338-5467

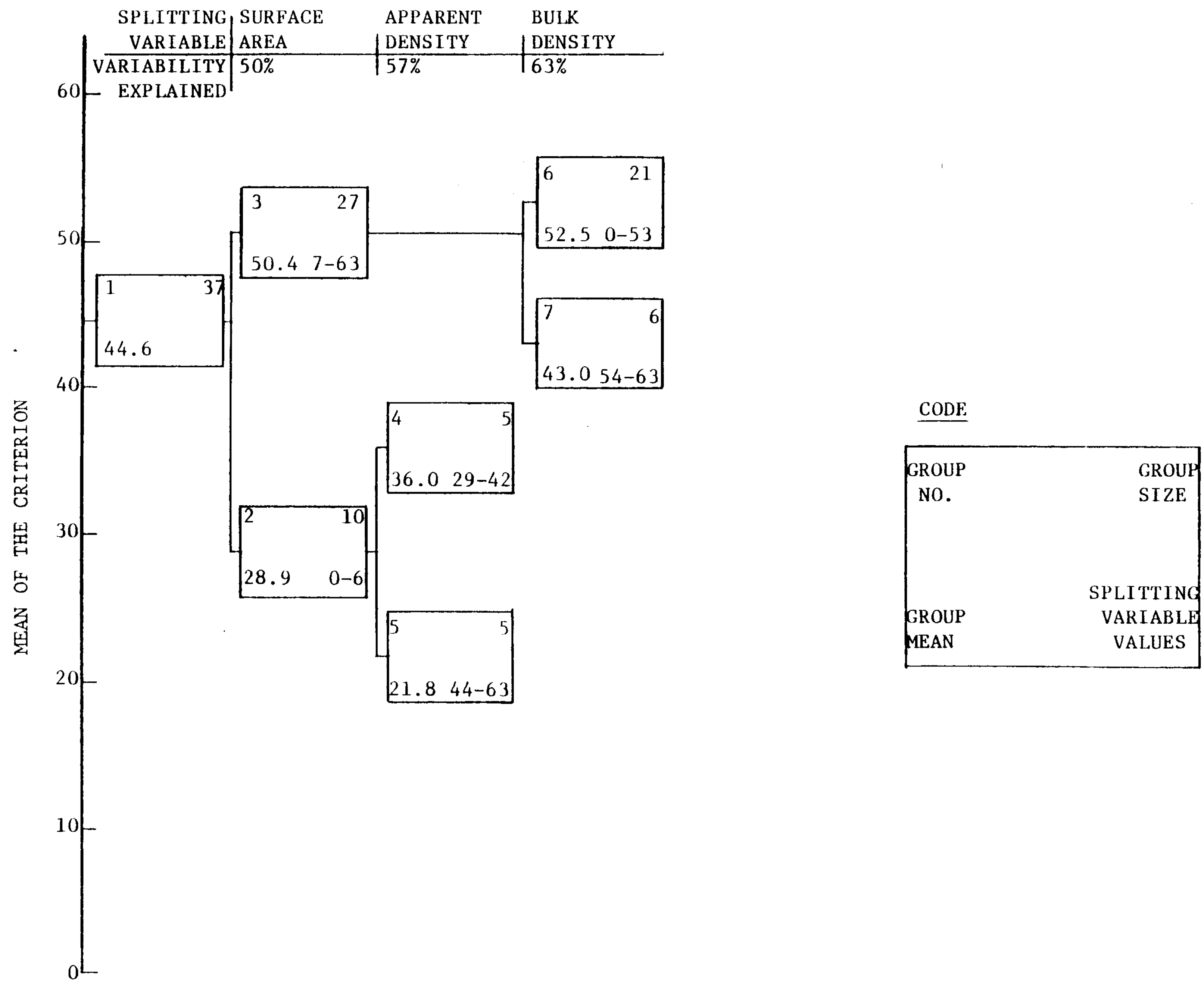


FIGURE 17. C-338 HYDROCARBON GAS VERSUS LABORATORY AND WELL LOG DATA

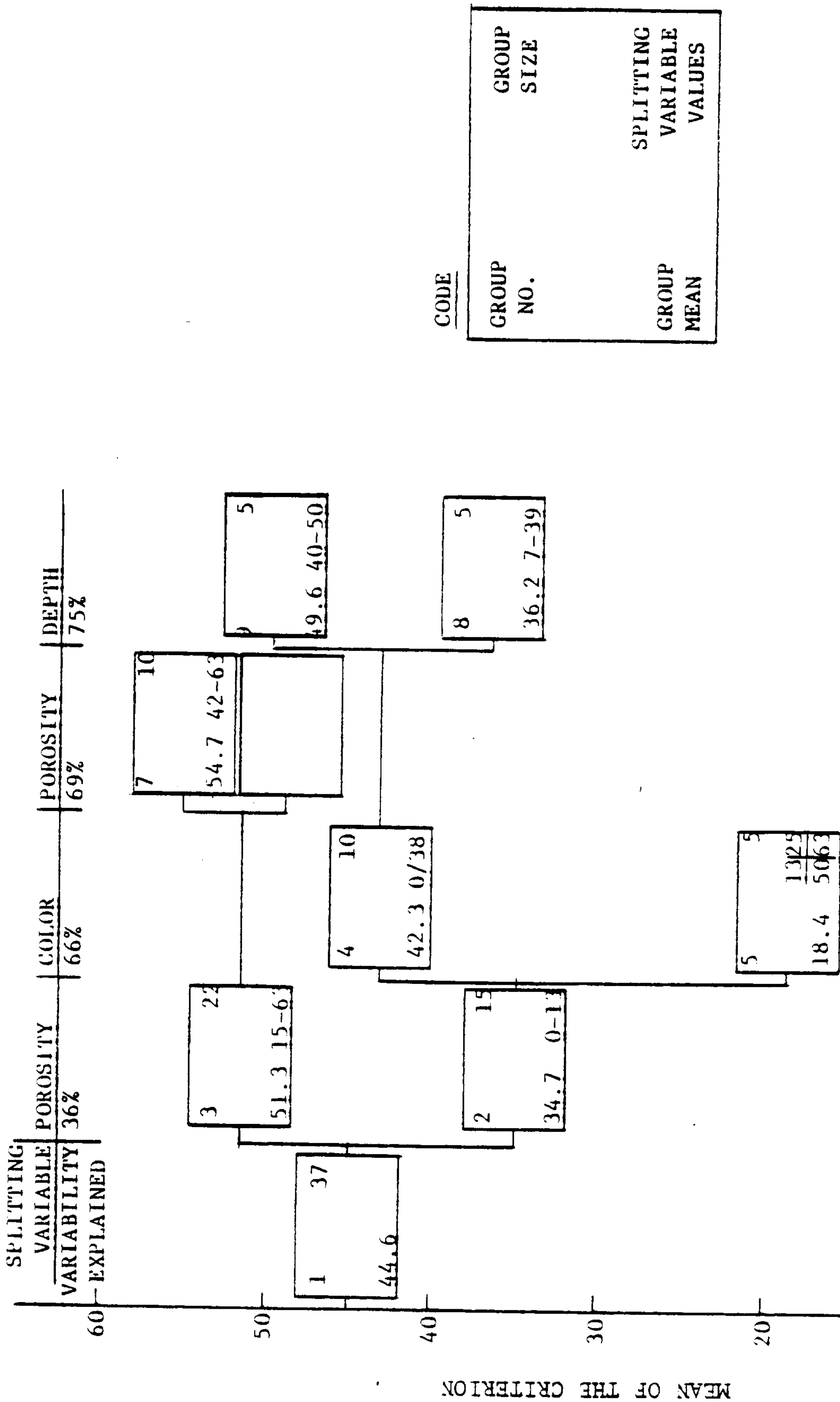


FIGURE 18. C-338 HYDROCARBON GAS VERSUS WIRE LOG DATA

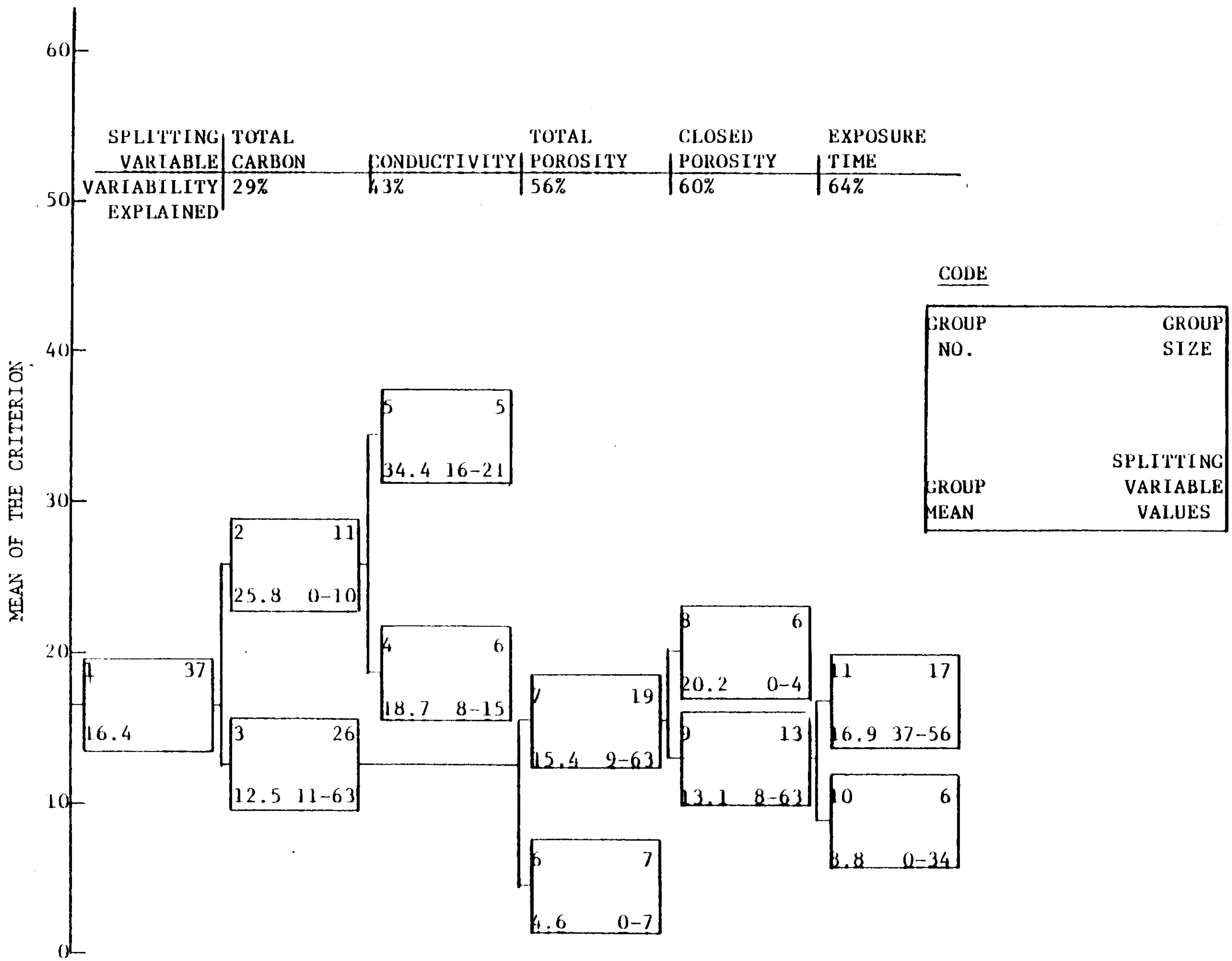


FIGURE 19. C-338 OPEN POROSITY VERSUS LABORATORY AND WIRE LOG DATA

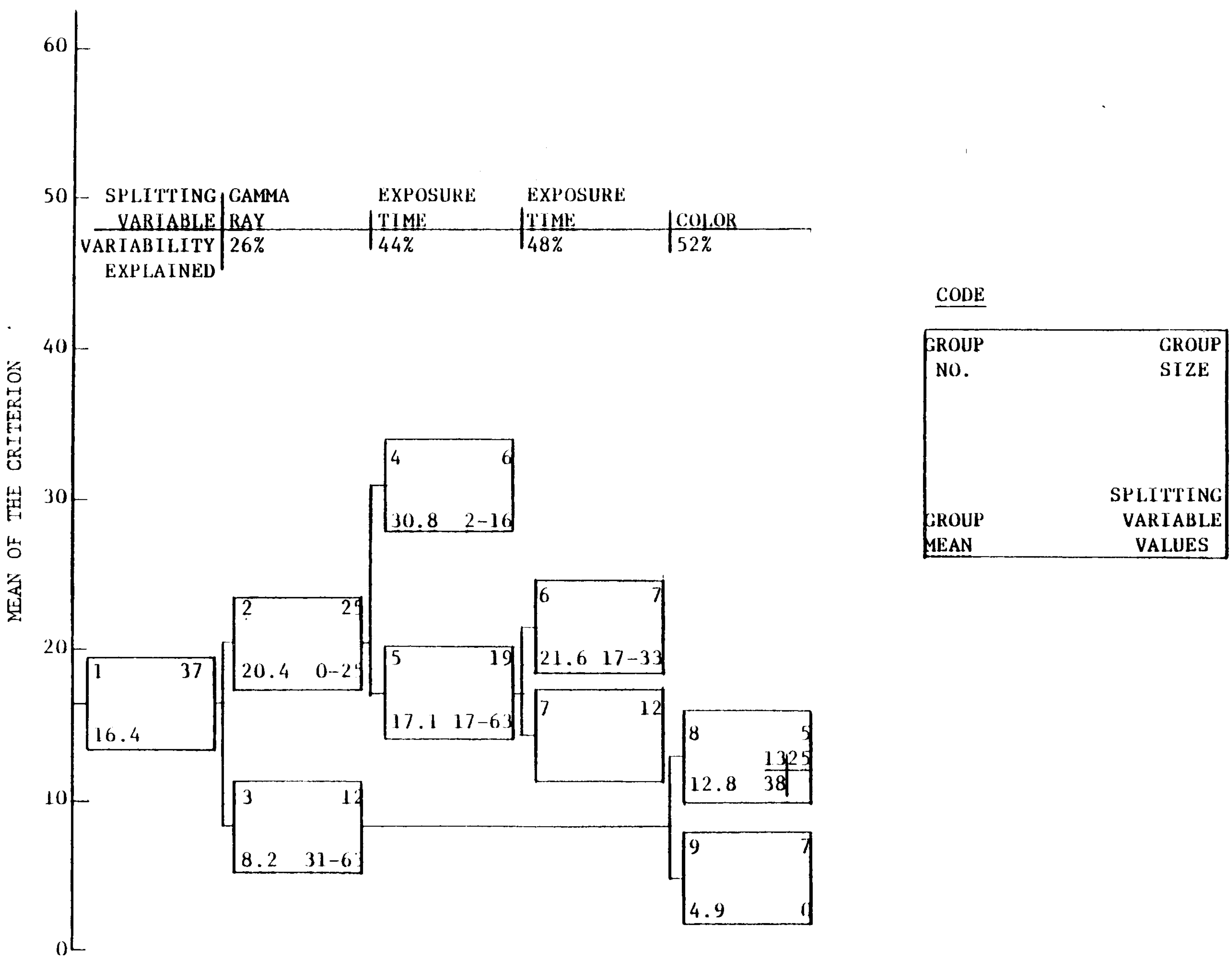


FIGURE 20. C-338 OPEN POROSITY VERSUS WIRE LOG DATA